High-frequency Environmental Tracer Data to Improve our Knowledge of Hydrological Functioning in Nested Mesoscale Catchments

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1. BACKGROUND

- Increasing challenge for hydrologists to provide process-based understanding of catchment behaviour at larger scales
- Natural tracers provide integrated insights into how catchments route water to river networks at larger spatial scales
- Typically weekly temporal resolution of tracer data leads to considerable uncertainty over its interpretation (Kirchner et al., 2004)

⇒ BUT: potential in recent technological developments - increasingly accurate, reliable, affordable (e.g. Malcolm et al., 2006; Tetzlaff et al., in press).

This poster reports the results of data collected by continuous water quality monitoring in the Feugh catchment (233km²), Cairngorms, NE Scotland used to examine the tracer response at fine temporal resolution to enhance our understanding of catchment hydrochemical response and, by inference, hydrological processes.

2. OBJECTIVES

The over-arching aim was examining how high frequency tracer data can enhance understanding of the hydrological and hydrochemical functioning of nested catchments.

Specifically we used continuous tracer data to assess:
(i) the scaled hydrological and hydrochemical response of catchments over a hydrological year.
(ii) the changing importance of different hydrological sources of runoff at different spatial scales, providing more insightful estimation of uncertainties.
(iii) the scaled influence of hydrological conditions on stream hydrochemistry under high and low flows.

3. STUDY SITE AND METHODOLOGY

- Altitude: 69 - 775 m.a.s.l, mean elevation 300 m.a.s.l, mean slope 8.6°, max. slopes> 40° (Fig. 1)
- Geology: mostly granite (78%), some metamorphic rocks (mainly pelites and psammites)
- Complex soil cover:
  (i) at higher elevationextensive plateaux areas dominated by hydrologically responsive peats (histosols) and peaty gleys (histic gleys) 60% of catchment),
  (ii) steeper catchment slopes: freely-draining brownsoils, humus iron podzols (haplic podzols) and deeper sub-alpine podzols (27% of catchment),
  (iii) river valleys: freely-draining alluvial soils (fluvisols)
- Landcover: dominated by heather (Calluna) moorland
- Mean annual discharge is 24.8 l s^{-1} km-2 (1985-2003)
- pH and specific conductivity were continuously (15 minutes) logged with Troll 9000XPE data loggers (In-Situ, Inc.) at two spatial scales – at 1 km² and 42 km², supplemented by inferred composition at 233 km²
- Strong relationship between H+ activity and Gran alkalinity concentrations (R^2 > 0.86) allowed to derive Gran alkalinity (closely approximates Acid Neutralising Capacity) from pH time series
- Using this high resolution tracer profile, and accommodating compositional uncertainty analysis (cf. Brewer et al., 2005), a two-component mixing analysis was carried out to estimate the relative importance of soil water and groundwater components to stream discharge.
- Additionally, weekly stable oxygen isotope ratio $\delta^{18}O$ (‰, parts per mille) used for mean residence times calculation

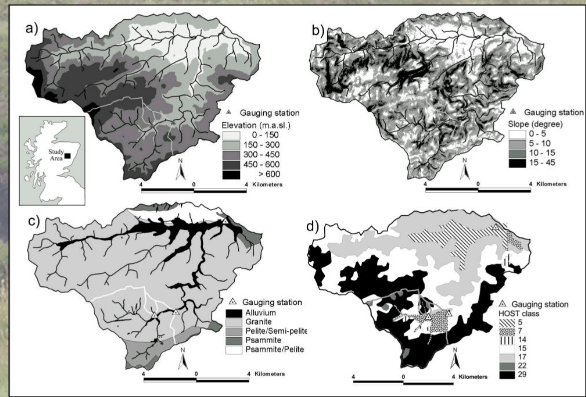

Fig.1: The Feugh catchment: (a) Topography, gauging sites and sampling locations, (b) Slope, (c) Geology, (d) HOST classes (5 = Humus Iron Podzol; 7 = Alluvial Soils; 14 = Gley; 15 = Peaty Gley, Peaty Podzol; 17 = Alpine soils, Humus Iron Podzol; 22 = Brown Ranker; 29 = Peat)

4. RESULTS

HYDROLOGICAL AND HYDROCHEMICAL CHARACTERISTICS AND RESPONSE

- Fine resolution data reveal patterns and effects of processes that are simply not available from more typical weekly or fortnightly sampling periods used in many hydrochemical studies (Fig. 2, using 100 random repeat samples from the continuous time series)
- All three sites are highly responsive to precipitation (Fig. 3)
- Clear relationship between pH-derived continuous Gran alkalinity time series with flow
- Storm flow: common origins as overland flow and shallow subsurface storm flow from the acidic surface horizons of peats and peaty soils (low GA)
- Low flow (high GA): groundwater dominated, more divergent between subcatchments - reflecting strong influence of geology and geochemistry

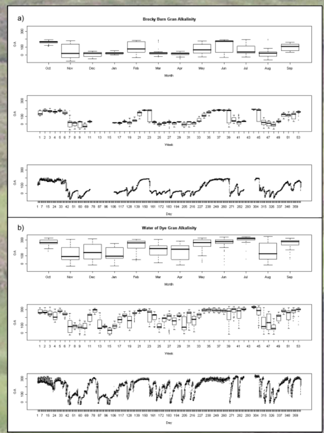

Fig. 2: Effect of sampling resolution on variability in Gran Alkalinity: (a) Brocky Burn (1.3. km²) and (b) Water of Dye (42 km²)

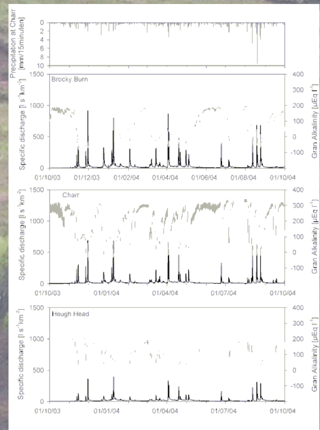

Fig. 3: Specific discharge and continuous Gran Alkalinity at (a) Brocky Burn, 1.3 km2; (b) at Charr, 42 km2 and (c) at Heugh Head, 233 km2 (c), showing precipitation at station at Charr

HIGH FLOW AND LOW FLOW VARIABILITY

- Gran alkalinity plotted against discharge shows very limited hysteresis (Fig. 4), which reflects constant storm event hydrochemistry dominated by acidic soil water of relatively constant composition with limited divergence in the response during recession.
- Gran alkalinity exhibits a threshold response; up to specific discharges of around 50-100 l s^{-1} km^{-2} Gran alkalinity decreases linearly with flow, above this concentrations are relatively consistent <0μeq l^{-1}.
- Lack of marked hysteresis is consistent with a threshold response to dominance of hydrochemically similar runoffsources in acidic peaty soils being activated (although antecedent conditions, storm event rainfall characteristics and atmospheric deposition result in some variability in the storm response)

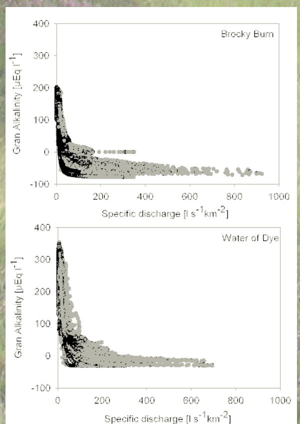

Fig. 4: Flow concentration plot of Gran Alkalinity at Brocky Burn and at Charr (Water of Dye)

ESTIMATION OF GROUNDWATER CONTRIBUTIONS AND MEAN RESIDENCE TIMES

- Increasing groundwater contribution to flows with increasing catchment scale (Table 1) - consistent with mean residence time estimates from isotope data and the catchment characteristics as the proportion cover of freely draining soils increases (Table 1, Fig. 6)

Catchment	Feugh	Water of Dye	Brocky Burn
km²	323	42	1.3
Mean groundwater contribution (%)	70	66	53
GW - contribution - 95% Credible interval, lower	59	72	62
GW - contribution - 95% Credible interval, upper	81	61	42
Mean residence time (days)	205	195	90
±95% Confidence Interval to annual flow	129	123	51

Table 1: Estimated percentage soil water and groundwater contributions in the Feugh and associated sub-catchments calculated from chemical hydrograph separations and mean residence times

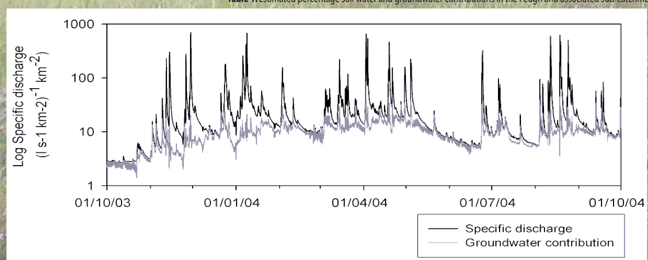

Fig.5 : Tracer-based hydrograph separation at Charr

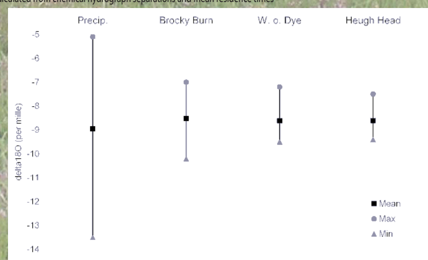

Fig. 6: Ranges in ?18O in precipitation and the three catchments investigated

5. CONCLUSIONS

- Results contributed to development of transferable approaches to tracer-based conceptualisation of streamflow generation processes at larger scales
- Continuous tracer data provided detailed insight of the scaled hydrological and hydrochemical response of these nested catchments (under high flow and low flow conditions)
- Threshold behaviour of runoff processes in larger storm events became clearer than with coarser sampling resolution
- Continuous water quality data represent a resource - and challenge - to hydrological modellers as an objective function in model evaluation
- High resolution profiles reveal subtlety of in-stream biogeochemical processing (diurnal variability), that may need to be incorporated into a wider range of water quality models pertinent to the influence of environmental change in upland catchments

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